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Explicit simulation of an artificial tracer experiment : what insights can be gained by assimilating tracer measurements in physically-based numerical models?

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Physically-based numerical models that simulate flow and solute transport in coupled surface water (SW) groundwater (GW) systems are important tools to manage alluvial hydrogeological environments. Estimation of model parameters commonly relies on calibration against measured hydraulic heads and boundary fluxes, such as streamflow. However, given the complexity of natural systems, hydraulic data alone cannot properly constrain the unknown parameters, potentially leading to high uncertainties in model predictions of interest. Calibrating model parameters jointly against solute and hydraulic data in physically-based models has the potential to reduce parameter non-uniqueness and associated predictive uncertainties, although the extent to which and in what contexts this is true remains an open question.

We present the results of assimilating measured tracer concentrations in a fully coupled physically-based model (HydroGeoSphere). A unique dataset was acquired over the course of a tracer experiment in 2021, during which the noble gas helium (He) was continuously injected into a Swiss pre-alpine river (river Emme, Bern) over a period of several weeks. High resolution measurements of dissolved He in both SW and GW formed the basis of the (re)calibration dataset for an existing SW-GW flow model, in which tracer flow and transport is now explicitly simulated.

We show how the inclusion of tracer data in the calibration process can lead to reductions in predictive uncertainties when compared to calibration against hydraulic data alone. In particular, we focus on model outputs which are most relevant to water resource management in alluvial systems, such as GW residence time, SW/GW exchange fluxes, and mixing ratios.